Institute of Polar Studies

Report No. 76

Environmental Histories from Whitefish and Imuruk Lakes, Seward Peninsula, Alaska

by

Jonathan Shackleton
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and
Department of Zoology

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ABSTRACT

Sediment cores from Imuruk and Whitefish Lakes, Seward Peninsula, Alaska, were analyzed for pollen and dated using radiocarbon techniques. The paleomagnetic study greatly extended the range of the radiocarbon dating by providing evidence for the occurrence of the Blake paleomagnetic event which occurred 100,000-125,000 years ago. Imuruk Core V appears to be about 140,000-150,000 years old. Radiocarbon dates show that the record was truncated about 10,000 years ago. Pollen analysis, supported by these dates, suggests that the Wisconsin in the Arctic consisted of three major phases: a cold period when the vegetation was dominated by Gramineae, Cyperaceae, and *Artemisia*, lasting from about 80,000 until 55,000 B.P. Then there was a warmer interstadial when *Betula*, *Alnus*, and *Picea* became much more abundant between 55,000 and 35,000 B.P. Finally there was another cold period with steppe-tundra vegetation which began about 35,000 B.P. and lasted until 10,000-15,000 B.P. This chronology is very similar to that suggested for Siberia. The dates are not precise and the history may be found consistent with the dating of glacial events from other parts of the world. There is evidence from Imuruk to suggest that the Wisconsin was preceded by a long period of declining temperatures during the Sangamon. The vegetation then consisted of shrub tundra with *Picea* and *Alnus* often above trace amounts.

The Whitefish Lake record spans at least the past 10,000 years. The pollen record, the first Holocene record from this region, reflects a vegetation in which Cyperaceae and *Alnus* are abundant. The record indicates that there was no significant climatic change during the Holocene.

This study provides the best dated, well documented, long Arctic pollen record that gives a good history of the major vegetation changes and, hence, a good indication of the nature of the climatic record of the Wisconsin in the Arctic.

ACKNOWLEDGMENTS

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TABLE OF CONTENTS

	Page
ABSTRACT	iii
ACKNOWLEDGMENTS	iv
LIST OF FIGURES	vi
LIST OF TABLES	vii
INTRODUCTION	1
Previous Studies	1
Site Descriptions	2
MATERIALS AND METHODS	5
Paleomagnetic Study	5
Pollen Analysis	5
Pollen Sum	8
Confidence Limits	8
Measurement of Pollen Influx	14
Radiocarbon Dating	15
RESULTS	19
Imuruk Core V Pollen Zones	19
Sand Layers	21
Length of Pollen Record	21
Core Location	21
Whitefish Pollen Zones	21
VEGETATION INTERPRETATION	23
Problems of Interpretation	23
Imuruk Lake	25
Vegetation History	25
Tundra Fires	27
Suggested Climatic History	27
Whitefish Lake	27
Vegetation History	27
Comparison to Other Selected Holocene Records from the Arctic	28
Suggested Climatic History	29
The Origin of the Alaska Spruce	29
DATING	31
Imuruk Lake	31
Radiocarbon Dating	31
Paleomagnetic Dating	33
Fission Track Dating	33
Whitefish Lake	35
Radiocarbon Dating	35
Paleomagnetic Dating	35
POLLEN ANALYSIS AND THE CLIMATIC RECORD FROM THE SEWARD PENINSULA DURING THE LATE PLEISTOCENE	37
Imuruk Core V and Whitefish Lake Core	37
Correlation With Other Evidence for Glacial Events in the Arctic	37
Correlation With Glacial Events Outside the Arctic	38
SUMMARY AND CONCLUSIONS	39
APPENDIX A	41
REFERENCES	45

LIST OF FIGURES

Figure		Page
1	Map of Seward Peninsula, Alaska, showing Imuruk Lake and Whitefish Lake sites	3
2	Map of Imuruk Lake indicating core sites I, II, IV, and V	6
3	Map of Whitefish Lake indicating core site X	7
4	Percentage pollen diagram for Imuruk Lake	Pocket
5	Percentage pollen diagram for Whitefish Lake . . .	Pocket
6	Changes in percentages of Gramineae and *Alnus* compared to increasing pollen sum at 42.5 cm, 103 cm, 300 cm, 340 cm, and 362 cm from Whitefish Lake	9
7	Changes in percentages of Cyperaceae and *Betula* compared to increasing pollen sum at 42.5 cm, 103 cm, 300 cm, 340 cm, and 362 cm from Whitefish Lake	10
8	Increase in numbers of pollen taxa compared to increase in the pollen sum at 42.5 cm, 103 cm, 340 cm, and 362 cm from Whitefish Lake.	14
9	Percentage curves of principal taxa from Imuruk Lake with bars representing 0.95 confidence limits	Pocket
10	Percentage curves of principal taxa from Whitefish Lake with bars representing 0.95 confidence limits	Pocket
11	Depth-age points for upper 1.5 m on Imuruk Lake cores	32

LIST OF TABLES

Table		Page
1	Total Numbers of Pollen Grains and Spores Counted at Each Sample Depth of Imuruk Core.	11
2	Total Numbers of Pollen Grains and Spores Counted at Each Sample Depth of Whitefish Core	13
3	Radiocarbon Dates From Imuruk Cores	16
4	Radiocarbon Dates From Whitefish Lake	17
5	Summary of Results of Paleomagnetic Study by Marino, 1977	34

INTRODUCTION

Long continuous pollen records combined with paleomagnetic studies are rare. Only workers on a 200 m core at Lake Biwa in Japan (Horie, 1974) and Mörner (1977) and Woillard-Roucoux (1977) on a 140,000 year record from a peatbog in the South Vosges Mountain region of northeast France have produced such long combined records. This study combines paleomagnetic investigations by Marino (1977) and pollen analysis on cores from Imuruk and Whitefish Lakes in the Seward Peninsula in western Alaska to provide a virtually continuous record which dates back for more than 100,000 years. There is still much controversy surrounding the chronology of the last ice age (Heusser and Shackleton, 1979). The results of this study are discussed with reference to this controversy. The Imuruk Lake record is re-examined in the light of current problems presented by Arctic pollen analysis. Whether Arctic pollen analysis is really a blunt instrument (Colinvaux, 1967a, at p. 208), or one that has a sharp cutting edge as claimed by Andrews and others (1979) is considered.

Previous Studies

The few pollen records from the Seward Peninsula are from Nome (Hopkins and others, 1960), Imuruk Lake (Colinvaux, 1964; Colbaugh, 1968), and Cape Deceit (Matthews, 1974).

The Nome record, obtained from discontinuous peat deposits, spans the last 13,000 years. The pollen indicates a vegetation which has been interpreted as suggesting that for the past 10,000 years the climate has differed little from the present.

Matthews' (1974) record from Cape Deceit is not a continuous record. It is derived from three unconformable stratigraphic units consisting primarily of organic silt interbedded with lenses of sand or gravel and peat horizons. A very tentative chronology is based primarily on the occurrence of mammal fossils. The oldest of the three formations, the Cape Deceit formation, is assigned on the basis of the small mammal taxa present to being pre-Cromerian in age, or about 400,000-900,000 years old. The discontinuities in the record, for example much of the Wisconsin period appears not to be represented, and the absence of adequate dating, greatly limit the value of this site.

Imuruk Lake provides a uniquely long and continuous record. Despite the occurrence of two anomalously young dates near the base of his eight meter core, Colinvaux (1964) suggested that the record extended back to the Sangamon or Yarmouth interglacial periods. Colbaugh (1968) re-examined part of Colinvaux's core and three other short cores from Imuruk Lake. Dates from the top of the cores established that the Holocene was missing from the record. She identified a mid-Wisconsin warm period that ended more than 34,000 years ago and occurred in the middle of Zone J. Zone i she assigned to Sangamon time. This study provides evidence to change the conclusions.

The examination of another long core from Imuruk Lake aimed to confirm and clarify the results of the previous studies. Combined with the paleomagnetic study, a greatly improved understanding of the chronology of the last glacial and interglacial events should be achieved. The Imuruk Lake record was truncated about 8,000-9,000 years ago (Colinvaux, 1964; Colbaugh, 1968). Tectonic warping lowered the lake level and wave action truncated the record by stopping the accumulation of fresh sediment. The record from Whitefish Lake spanning at least the past 10,000 years fills in the missing Holocene section.

Site Descriptions

Imuruk Lake (65°21'36"N, 163°12'W) is irregularly shaped, about 13 km across, nowhere deeper than 3 meters, with surface area of 70 km^2, and located at 311.3 m elevation in an unglaciated area of the Seward Peninsula (Fig. 1). The basin was formed by basaltic lava flows and the volcanics are believed by Hopkins (1963) to be mid-Pleistocene in age. The drainage basin is approximately 285 km^2 (Hopkins, 1959a).

The vegetation today consists of tussock tundra. In the classic work on Arctic vegetation, Britton (1957), divided Arctic vegetation into five major types. Imuruk vegetation would be included in the dwarf shrub heath type. Tussocks of *Eriophorum* spp. dominate the areas where the soil is silty and well drained. In rocky places and areas of thin soil the vegetation is dominated by *Betula nana* and heaths (Colinvaux, 1964). The nearest spruce trees are about 25 km to the east in the Kugruk River Valley (Racine, pers. comm., June 1979). Alder (*Alnus crispa*) grows in the lower Imnachuk Valley about 40 km to the north (near Deering) and tens of kilometers to the east (Colinvaux, pers. comm.). Thickets of *Salix pulchra* are prominent in the lake area expecially along the water courses.

Whitefish Lake (66°24'N, 195°18'E) occupies a maar on Cape Espenberg in the north of the Seward Peninsula. The lake is roughly circular with an estimated maximum depth of 6 meters (Colinvaux, pers. comm.), a surface area of about 7 km^2 and has a surface elevation of 12.2 meters (Fig. 1).

The vegetation today consists of tussock tundra (Colinvaux, pers. comm.). There is an extensive beach community on the lip of the crater, probably up to 50 meters wide in places. Alder bushes

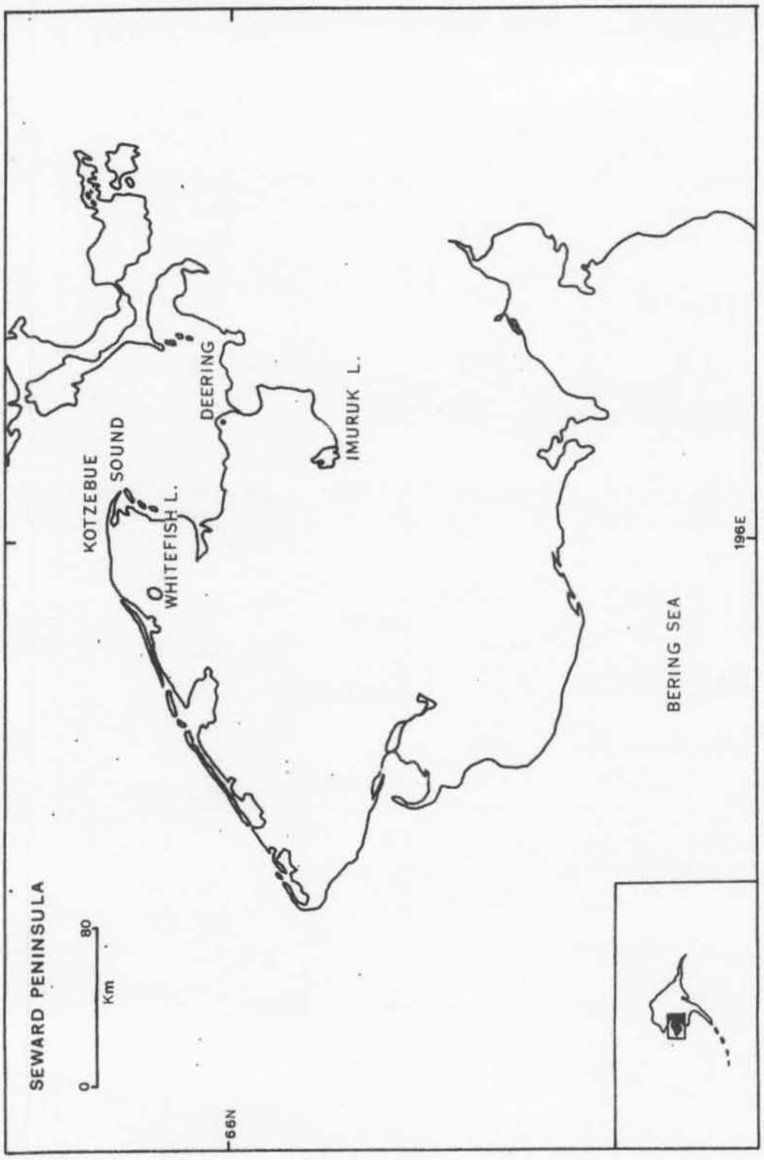

Figure 1. Map of Seward Peninsula, Alaska, showing Imuruk Lake and Whitefish Lake sites.

up to 1 meter high and willow bushes grow very scattered in the drainage basin. Alder is common in this region near the maar lakes and grows on the ash deposits (Racine, pers. comm., June 1979). Dwarf birch is generally as prominent as at Imuruk. There is no spruce or poplar in the area.

MATERIALS AND METHODS

Imuruk Lake Core V was obtained in August 1960 by P. A. Colinvaux using a Livingstone piston sampler. It was collected at the mouth of Salix Bay, 1 meter away from Core IV (which was analyzed by Colbaugh, 1968). Figure 2 indicates core locations. The total core length, as measured by Marino (1977), was 779.3 cm.

The Whitefish core was collected by Colinvaux, Hopkins, and Livingstone in June 1974 from one side of the lake (Fig. 3). The total length of the core was 540 cm.

Both cores were stored in a coldroom at $4^{o}C$.

Paleomagnetic Study

This part of the study was carried out and described in detail by Marino (1977). The cores were subsampled, following X-radiography of the intact cores to ascertain banding patterns, effects of desiccation or flowage and the effects of coring on the sediments. These subsamples were held in 2.5 cm long X 2.2 cm internal diameter transparent plastic cylinders capped on both ends with Parafilm. The Imuruk core was sampled where possible and the remainder of the core was discarded. The bottom 50 cm of the core was not sampled because the material was too dried out and crumbly. The Whitefish core was similarly sampled and the remainder of the core is stored in Colinvaux's coldroom.

Pollen Analysis

Samples of sediment of 1.0 cc (the preferred size for Imuruk) or 0.5 cc (the preferred size for Whitefish) were removed and measured for volume in 0.5 cc steel cylinders. One weighed Eucalyptus pill (from batch #903722 supplied by L. J. Maher, Jr., for whom they were made by Stockmarr) was added to each sample (Maher, 1977). The samples were then prepared using the acetolysis method of Erdtman described in Faegri and Iverson (1975) and the bromoform method of Frey (1955). Samples were also heated with 48 percent concentrated hydrofluoric acid. Stepwise details of the methods used are contained in Appendix A. The pollen was mounted in silicone oil and counted using a Leitz Ortholux microscope with 10X eyepieces and 25X or 40X apochromatic objectives. A tube factor gives 500X when using the 40X objective.

Usually a total of between 200-250 pollen grains was counted per slide. This choice of pollen sum is justified in a separate section below. The identification of pollen was assisted by the

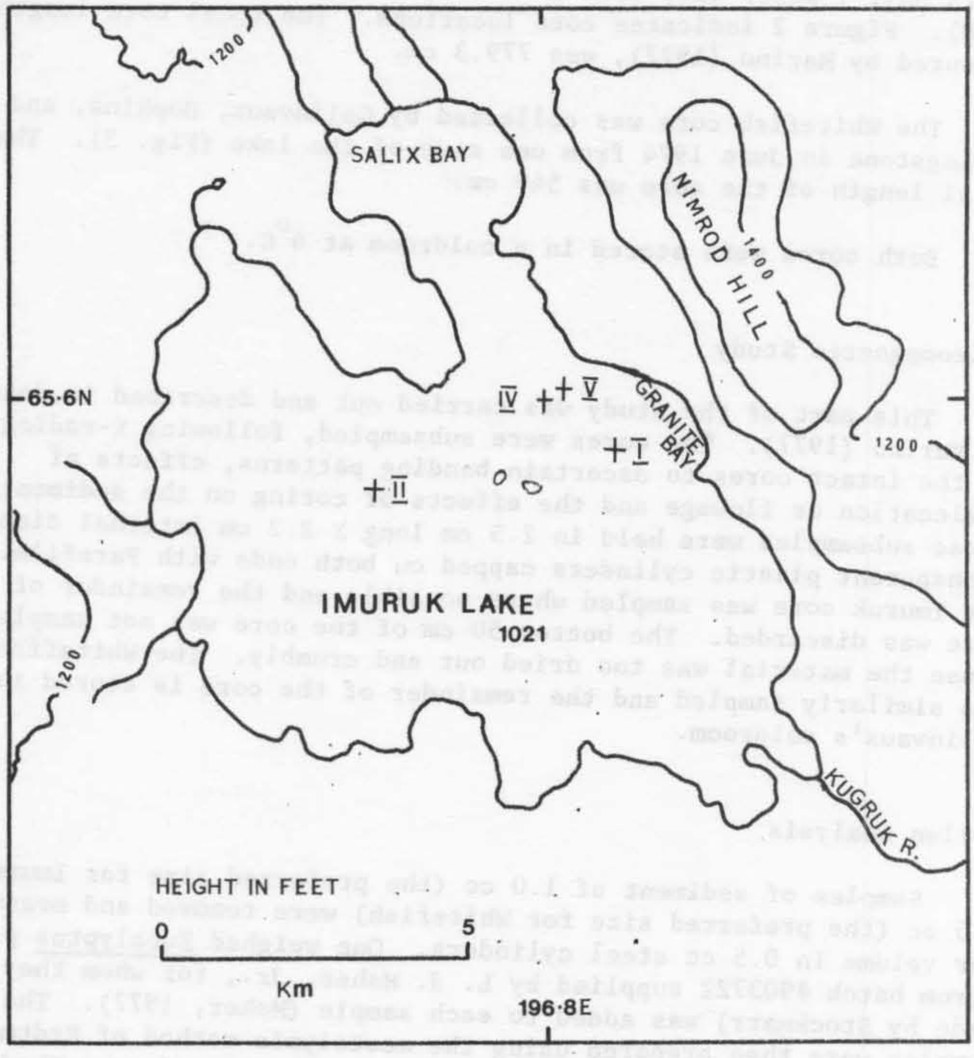

Figure 2. Map of Imuruk Lake indicating core sites I, II, IV and V.

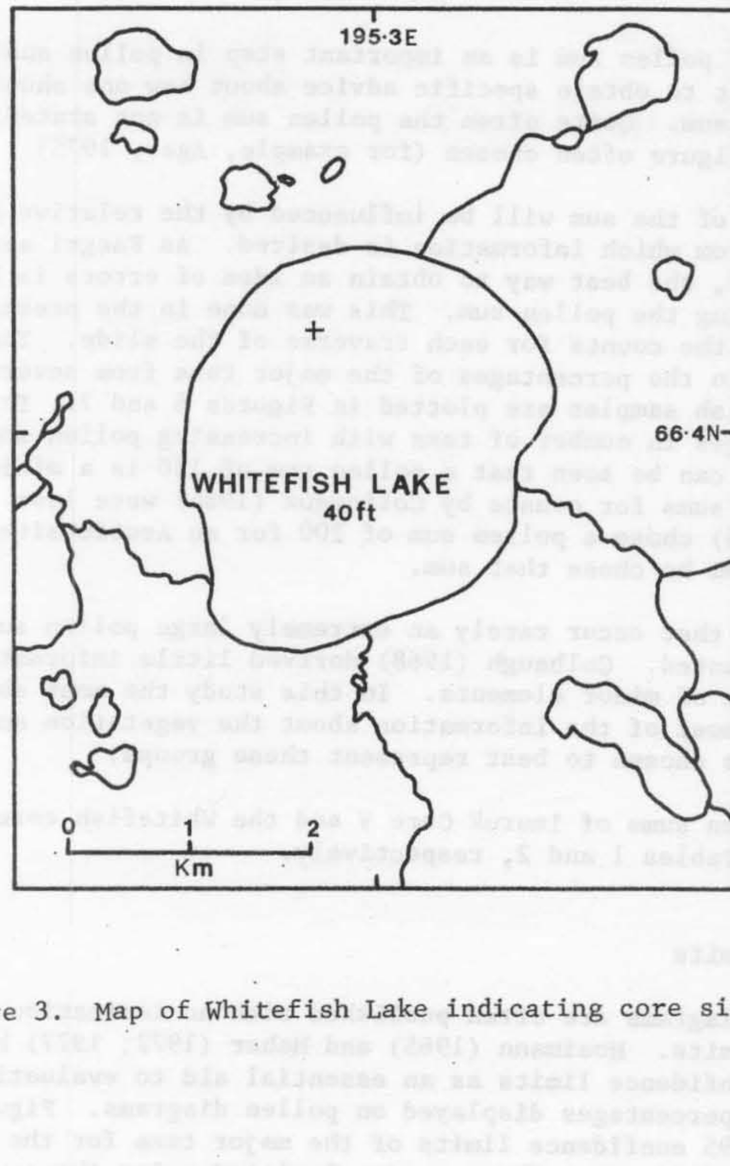

Figure 3. Map of Whitefish Lake indicating core site X.

advice of Colinvaux and an extensive reference collection in his laboratory. Pollen percentages were calculated on the basis of a pollen sum which excluded aquatic pollen types, spores, and algae. Spores were expressed as a percentage of the sum of pollen and spores. Percentage diagrams are presented for Imuruk and Whitefish in Figures 4 and 5.

Pollen Sum

Choice of pollen sum is an important step in pollen analysis. It is difficult to obtain specific advice about how one should decide on the pollen sum. Quite often the pollen sum is not stated. Three hundred is a figure often chosen (for example, Ager, 1975).

The size of the sum will be influenced by the relative abundances of the taxa from which information is desired. As Faegri and Iversen (1975) suggest, the best way to obtain an idea of errors is by gradually increasing the pollen sum. This was done in the present study by separating the counts for each traverse of the slide. The cumulative changes in the percentages of the major taxa from several randomly chosen Whitefish samples are plotted in Figures 6 and 7. This is also done for changes in number of taxa with increasing pollen sum in Figure 8. It can be seen that a pollen sum of 150 is a minimum. Many of the pollen sums for counts by Colinvaux (1964) were less than 150. Schweger (1976) chose a pollen sum of 200 for an Arctic site but does not discuss how he chose that sum.

For taxa that occur rarely an extremely large pollen sum would have to be counted. Colbaugh (1968) derived little information from the occurrence of minor elements. In this study the most abundant taxa provide most of the information about the vegetation and so the pollen sum was chosen to best represent these groups.

The pollen sums of Imuruk Core V and the Whitefish core are presented in Tables 1 and 2, respectively.

Confidence Limits

Pollen diagrams are often published with no indication of data confidence limits. Mosimann (1965) and Maher (1972; 1977) have urged the use of confidence limits as an essential aid to evaluating the precision of percentages displayed on pollen diagrams. Figures 9 and 10 display 0.95 confidence limits of the major taxa for the Imuruk and Whitefish diagrams. These were calculated using the equations provided by Mosimann (1965).

Figures 4, 5, 9, and 10 are at the back cover pocket.

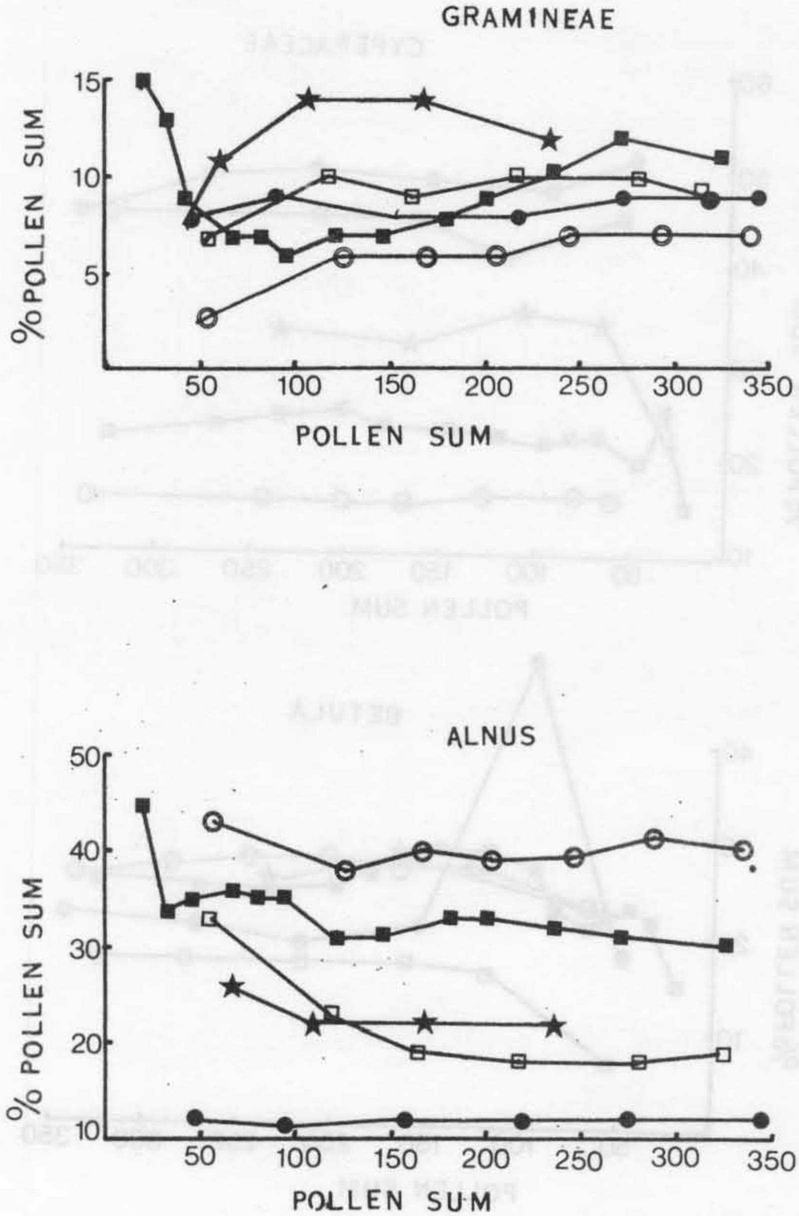

Figure 6. Changes in percentages of Gramineae and <u>Alnus</u> compared to increasing pollen sum at 42.5 cm. (□), 103 cm. (•), 300 cm. (*), 340 cm. (■), and 362 cm. (O), from Whitefish Lake.

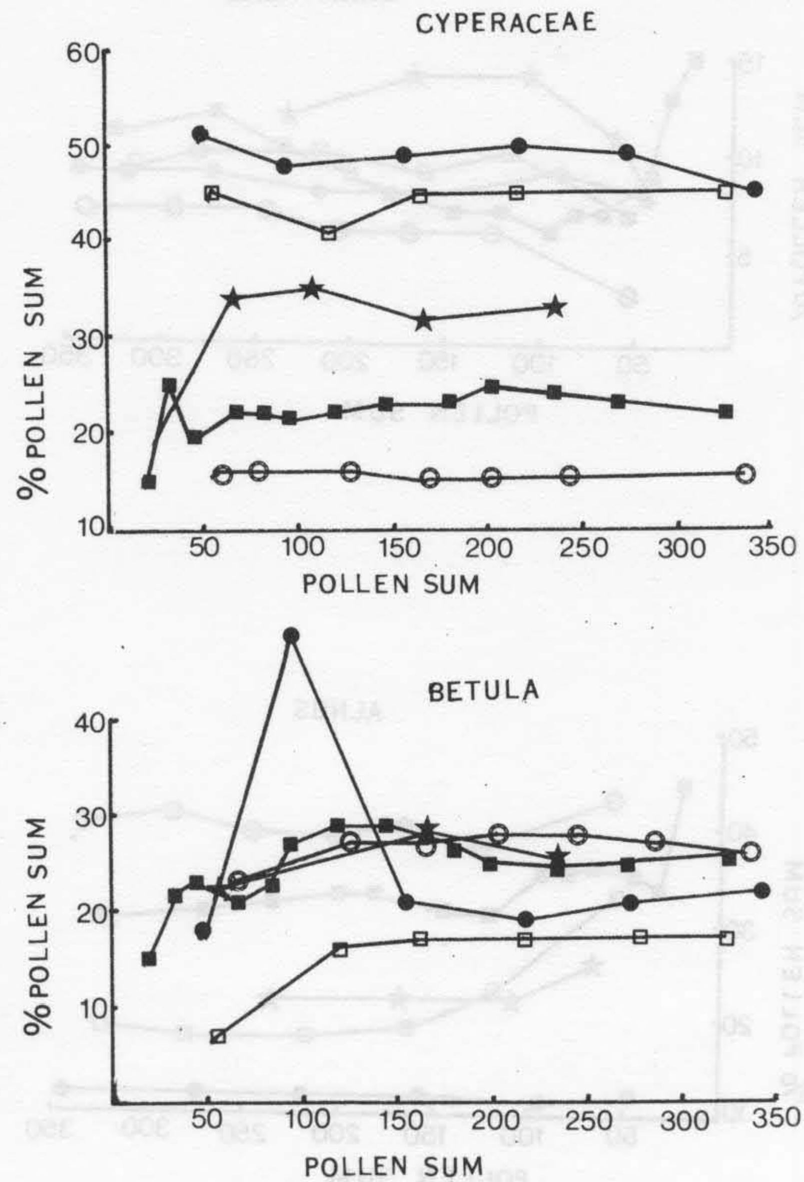

Figure 7. Changes in percentages of Cyperaceae and Betula compared to increasing pollen sum at 42.5 cm. (□), 103 cm. (•), 300 cm. (*), 340 cm. (■), and 362 cm. (O, from Whitefish Lake.

TABLE 1. Total Numbers of Pollen Grains and Spores[a] Counted at Each Sample Depth of Imuruk Core

Depth in cm.	Pollen Sum	Spore Sum	Depth in cm.	Pollen Sum	Spore Sum
3.5	175	36	315.6	351	100
6.0	216	33	320.1	208	63
88.9	196	20	327.1	209	32
94.5	288	29	329.6	273	90
104.7	252	16	336.1	287	39
118.0	238	35	346.9	210	44
120.5	205	21	349.4	234	69
135.5	201	10	355.9	290	21
143.4	255	8	361.3	208	10
151.5	156	6	367.9	213	18
157.6	179	7	372.9	247	10
160.1	214	9	383.9	232	10
173.6	185	6	393.3	243	26
184.2	277	22	400.6	210	4
199.0	267	15	408.1	307	8
210.5	343	16	417.5	210	11
221.8	181	19	429.9	254	9
233.5	231	73	432.4	204	6
243.1	212	97	442.1	210	10
259.8	248	75	451.1	255	5
269.5	294	64	462.6	238	17
279.9	332	95	474.1	265	13
292.9	305	92	483.6	236	14
304.1	256	101	493.6	239	16

TABLE 1.--Continued

Depth in cm.	Pollen Sum	Spore Sum	Depth in cm.	Pollen Sum	Spore Sum
499.0	220	14	614.1	215	47
502.1	207	19	623.1	204	76
515.0	333	86	633.6	215	29
518.1	233	15	641.1	208	87
539.0	219	34	644.4	239	93
541.6	252	48	655.1	201	27
546.1	203	21	664.6	202	70
548.0	243	42	674.9	212	65
558.0	234	57	683.8	147	34
566.3	222	47	694.1	222	43
571.0	220	72	704.1	136	17
581.0	224	72	717.2	226	46
591.1	204	74	721.7	206	33
602.6	222	103	725.6	209	26

[a]Spores include Sphagnum, pteridophyte and other moss spores.

TABLE 2.--Total Numbers of Pollen Grains and Spores[a] Counted at Each Sample Depth of Whitefish Core

Depth in cm	Pollen Sum	Spore Sum	Depth in cm.	Pollen Sum	Spore Sum
18.0	224	13	280.0	244	13
27.0	212	2	290.0	235	8
32.0	269	4	300.0	236	20
42.5	321	7	310.0	221	14
47.0	245	4	320.0	222	13
57.5	327	7	330.0	217	11
67.0	243	6	340.0	326	19
83.3	233	11	350.0	224	9
93.0	224	11	362.0	335	18
103.0	343	22	369.5	256	9
113.0	220	12	380.0	236	6
123.0	198	14	385.0	227	11
133.0	220	18	398.0	315	12
143.0	331	19	408.0	272	14
153.0	251	8	418.0	218	5
163.0	264	6	428.0	220	14
179.5	212	10	438.0	298	22
189.5	210	13	453.0	259	16
199.5	293	20	465.0	217	12
209.5	224	11	478.0	311	16
222.0	253	8	488.5	258	11
233.0	366	11	498.5	213	8
243.0	223	11	508.5	234	15
254.0	231	8	522.0	229	13
270.0	235	10	531.0	218	6

[a]Spores include _Sphagnum_, pteridophyte and other moss spores.

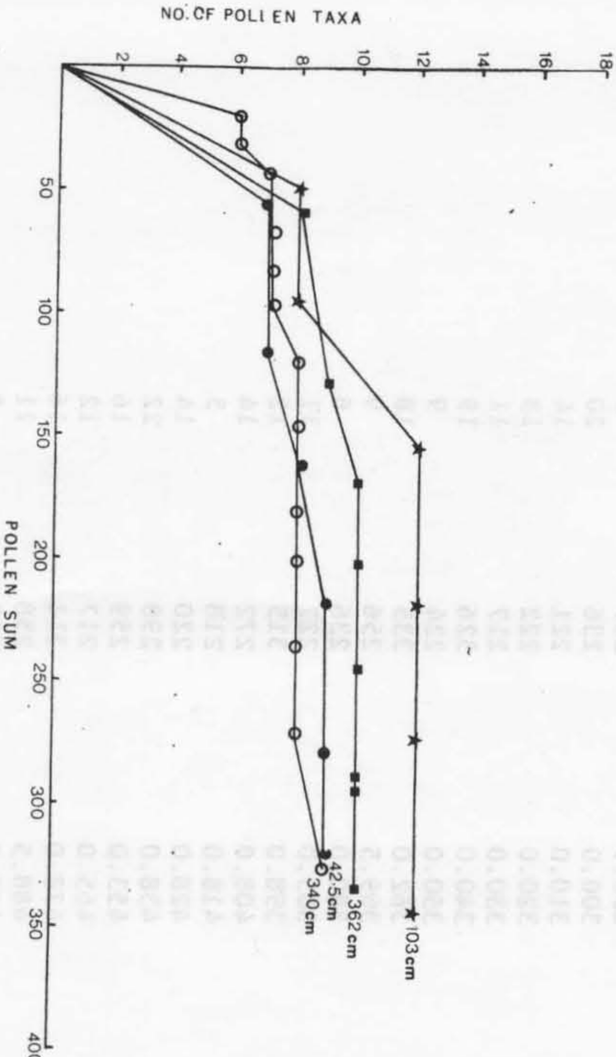

Figure 8. Increase in numbers of pollen taxa compared to increase in the pollen sum at 42.5 cm. (●), 103 cm. (★), 340 cm. (○), and 362 cm. (■), from Whitefish Lake.

Measurement of Pollen Influx

Davis (1967) was the first to make routine use of determinations of pollen influx. Pollen counts can then be expressed as numbers of grains of a taxa/cm^2/year. The advantages of such determinations are outlined by Davis and others (1973). Such determinations are only useful if the sedimentation rate is constant or if the fluctuations can be determined by closely spaced radiocarbon dates.

The sampling procedures are assumed to yield samples of equal volume. A known number of "exotic" Eucalyptus pollen grains are introduced in pill form. When the samples are counted, the number of exotic pollen grains is recorded along with the other grains.

The total number of pollen grains per cm^3 of sediment can then be calculated following the method of Maher (1972) where:

N = Number of Eucalyptus grains added to sample.

R = Ratio of the number of pollen grains of taxon X counted to number of grains of Eucalyptus recorded during counting.

V = Volume of sediment sample in cm^3.

So that,

$$\frac{NR}{V} = \text{Number of grains of taxon } X/cm^3 \text{ of sample} = \text{pollen concentration.}$$

If the sedimentation rate S (expressed in cm/yr.) is determined from radiocarbon dates on the core, the rate of pollen influx can be determined from the equation:

$$\frac{NSR}{V} = \text{Pollen grains}/cm^2/yr.$$

Radiocarbon Dating

Radiocarbon dating was performed at commercial laboratories. The results for Imuruk Lake cores obtained during previous studies are presented in Table 3. Results for Whitefish Lake obtained during the present study are presented in Table 4. On the basis of the radiocarbon dates so far available, the assumption of uniform sedimentation rates necessary to calculate influx rates cannot be made.

TABLE 3.--Radiocarbon Dates From Imuruk Cores

Laboratory Number	Submitted By	Age in Years B.P.	Source of Sample cm
I[a]-3629	Colbaugh, 1968	8,620± 300	I, 4-20
y[b]-1144	Colinvaux, 1962	12,355± 160	I, 30-40
I-588	Colinvaux, 1962	13,250± 700	I, 50-60
I-3630	Colbaugh, 1968	12,160± 300	II, 5-19
I-3631	Colbaugh, 1968	10,700± 150	IV A, 5-12
I-3632	Colbaugh, 1968	11,910± 180	IV A, 96-115
I-3662	Colbaugh, 1968	25,850±2,400	IV A, 172-184
DIC[c]-906	Marino, 1977	10,370± 175	V, 17-26.5
DIC-907	Marino, 1977	10,780± 580	V, 70.7-80.7
DIC-908	Marino, 1977	$11{,}330\pm^{1{,}060}_{1{,}210}$	V, 120.5-133.0
DIC-909	Marino, 1977	24,190+960-1,070	V, 160.1-173.3
DIC-910	Marino, 1977	26,460+2,670-4,030	V,199.0-209.8

[a]Isotopes Inc., Westwood, New Jersey.

[b]Yale Radiocarbon Laboratory, New Haven, Connecticut.

[c]DICARB Radioisotope Co., Chagrin Falls, Ohio

TABLE 4.--Radiocarbon Dates From Whitefish Lake

Laboratory Number	Depth cm.	Age in Years B.P.	Submitted By
GX6114[a]	175	6,075±210	Shackleton, 1979
GX6113	358	10,425±340	Shackleton, 1979
GX6112[b]	530	9,390±350	Shackleton, 1979
GX6112[c]	530	10,200±550	Shackleton, 1979

[a] Geochron Laboratories, Cambridge, MA.

[b] This date was reported by Geochron in January 1979

[c] This adjusted date for the same sample was reported by Geochron in June 1979.

RESULTS

Imuruk Core V Pollen Zones

The pollen diagrams in this study are divided into zones to aid in the description and interpretation of the pollen record. These zones must be compared with Livingstone's (1955) three zone sequence for the Arctic and with Colinvaux's (1964) zones for Imuruk Lake Core 1.

Livingstone (1955) established a three zone sequence for post-glacial time in the Brooks Range. Zone I has a pollen rain dominated by herbs and little birch. In Zone II birch rises to a maximum with a decrease in herb pollen. Zone III was characterized by a rise in alder pollen with a decline in birch. Colinvaux (1964) assigned his zones to Livingstone's zone types, although he included spruce or alder in Zone III. The scheme is only useful as a very broad classification and is of limited value if spruce and alder are interchangeable. High values of one or the other can represent distinctively different vegetation types. The high percentages of *Artemisia* pollen found in pre-Holocene times is not a characteristic of Livingstone's sequence. Therefore, Livingstone's scheme is not used in this study.

Colinvaux (1964) names his zones alphabetically starting with A at the bottom and going to L at the top. Colbaugh (1968) extended this to M. This is a good match between Colinvaux's Zones M-G and Core V, but the fluctuations on Colinvaux's Zones A-G are not present on Core V.

Zone G. 740-535 cm.

This zone generally resembles Colinvaux's (1964) Zone G, both being similar to Livingstone's Zone II. There are differences in detail and Imuruk V is divided into four sub-zones:

G^{1}. 740-680 cm. Characterized by high levels of birch, 2-5 percent of *Artemisia*, 30-40 percent Gramineae, 10-20 percent Cyperaceae and 5 percent Ericaceae. Spruce and alder are both present but in percentages of 5 percent or less suggesting they were far from the lake.

G^{11}. 680-585 cm. This zone maintains similar patterns to G^{1} except that there is a gradual increase in *Artemisia* from a 2 percent to a fairly consistent level of about 15 percent. An increase of this magnitude is not present in Core 1.

G^{111}. 585-535 cm. This is a zone characterized by a gradual decline of birch from 25 to 10 percent and a decline in alder pollen to trace amounts. The upper part of the zone is marked by a sharp decline in *Artemisia* from 36 to less than 2 percent and a sharp increase in Cyperaceae from 19 to 51 percent just below the ash fall.

535-52 cm. Ash Layer. This apparently could not be identified in Core I.

G^{IV}. 520-500 cm. This zone is characterized by a brief increase of birch to 18 percent and alder and spruce to 11 percent.

Zone H. 500-356 cm.

This is the zone in which there is least agreement with Colinvaux's zones in Core 1. It is presumed to include the time span that is represented by his zone H, although the sedimentation rates appear to be very different.

In Imuruk Core V it is subdivided into H^I, H^{II}, H^{III}:

H^I. 500-430 cm. This sub-zone is marked by low levels of alder, birch, and spruce with high percentage of grasses, sedges, and *Artemisia*.

H^{II}. 430-408 cm. This is a short sub-zone marked by a brief appearance of alder of up to 6 percent and small increases in birch and spruce. This cannot be matched in Colinvaux's zones.

H^{III}. 408-356 cm. This sub-zone has more persistently increasing levels of birch up to 9 percent and the appearance in the upper 30 cm of increasing levels of alder while the other taxa remain unchanged.

Zone i. 356-174 cm.

This zone, which matches Colinvaux's (1964) Zone i, is divided into two sub-zones i_1 and i_2.

Zone i_1. 356-243 cm. This sub-zone is marked by high levels of arboreal pollen. The early birch and alder peaks are followed closely by a very rapid increase in spruce up to 44 percent which then settles to 15-20 percent for most of the zone. Ericaceae pollen stays at 5 percent throughout the zone and Cyperaceae, Gramineae, and *Artemisia* pollen percentages drop.

Zone i_2. 243-174 cm. This sub-zone is characterized by a gradual decline of birch pollen to less than 10 percent and alder and spruce to trace levels. Gramineae and Cyperaceae show large increases and *Artemisia* shows a small but fluctuating increase up to a maximum of 11 percent. These zones match those from Core I.

Zone J. 174-?90

This zone matches Zone J in Core I and Core IV and resembles Livingstone's Zone I. It is characterized by high levels of herbaceous pollen, birch levels of about 10 percent and trace levels of alder, spruce, and ericaceous pollen.

90-0 cm. The samples in this part of the core contained so much Pediastrum that pollen counts were not feasible except in two samples. These were at 3.5 cm and 6.0 cm, and they resemble Colinvaux's Zone L. The upper sample has a pollen spectrum which resembles that of surface samples collected by Colinvaux (1964).

Why are there differences between the cores?

Sand Layers

Very conspicuous in Imuruk Core I are five thick sand layers all occurring below 3 meters. None of these sand layers are present in Core V. Colinvaux (1964) ascribes these sand layers to the movement offshore by wave action of Granite Bay beach sands at times of low lake level. Influx of sand into the sediments could result in very different sedimentation rates compared to Core V and so alter the pollen peaks.

The associated wave action in shallow water could result in different patterns of deposition and resuspension of pollen grains. Differential deposition of pollen grains in different parts of the same lake has been clearly shown by workers such as Davis and others (1971) and Bonny (1978).

Length of Pollen Record

Comparison of pollen zones in Core I and Core V strongly suggest that despite having similar core lengths and despite the presence of sand layers in Core I, Core V does not include Zones A-F of Core I.

Core Location

Cores I and V were obtained 1.4 km apart. In the absence of details of the lake's morphometry and sedimentation patterns, it would be unreasonable to expect that both cores should have identical pollen spectra.

Whitefish Pollen Zones

The Whitefish pollen diagram is characterized by high levels of Cyperaceae, usually between 30 and 60 percent, Alnus is most often between 15 and 25 percent, Betula between 10 and 30 percent, and levels of Gramineae are usually less than 10 percent. The pattern is fairly uniform throughout the diagram. The diagram does not closely resemble any of the zones on the Imuruk diagram. Significant differences are the Cyperaceae: Gramineae ratio of 5-10:1; at Imuruk this ratio is usually 0.5:1. The co-occurrence of high levels of Cyperaceae with 15-25 percent Alnus is never a feature of the Imuruk diagram. The Whitefish diagram bears the most resemblance to Livingstone's Zone III, although the herb component is much higher at Whitefish.

VEGETATION INTERPRETATION

Problems of Interpretation

There are several important problems to be considered when discussing Arctic pollen diagrams. These problems are: (1) under and over representation of certain elements of the vegetation; (2) the inability to identify many taxa to species level; (3) the separation of regional and local pollen rain; (4) the complicating effects of differential plant migration rates, multiple plant refugia, and changing combinations of local environmental factors; and (5) the difficulties of using modern plant distributions and surface pollen samples as analogues of past plant distributions.

Tundra vegetation has many elements that are absent from the pollen rain or are present in such low amounts that standard pollen sums are inadequate to derive reliable quantitative estimates of their representation. Lichens and mosses, Ericaceae, Leguminosae, Caryophyllaceae, and Dryas spp. are often significant elements of the vegetation but are very under-represented in the pollen diagram. Of the important arboreal species in the Arctic, Populus is a major problem. Sangster and Dale (1961; 1964) and Havinga (1964) demonstrated that Populus pollen grains corrode rapidly under oxidizing conditions. Mott (1978) reviews the occurrence of Populus in late-Pleistocene spectra from Canadian Arctic sites. Populus is found in large amounts at some sites and not at others. He suggests that if reducing conditions prevailed at the site of deposition, Populus pollen would have a better chance of being preserved. This hypothesis is borne out by several studies including Ritchie (1977). Populus grows on the Seward Peninsula (Hulten, 1968) and grows in the Inmachuk Valley north of Imuruk Lake (Colinvaux, pers. comm.). Populus pollen has never been found in any Imuruk Lake samples.

Studies by Ritchie (1974; 1977) indicate that certain pollen types are highly over-represented when compared to gross cover values of main vegetation types. Such taxa include birch, alder, and Cyperaceae.

It is impossible to identify many of the Arctic taxa to species level. Several of the major taxa that occur in the pollen record can only be identified to family, e.g., Cyperaceae and Gramineae. Hulten (1968) lists more than 90 species of Gramineae and 110 species of Cyperaceae that appear to be native to Alaska. This problem also applies to Artemisia which occurs at high levels in parts of the diagram. Hulten (1968) lists 8 species of Artemisia that have been found on the Seward Peninsula, but Artemisia pollen can, as yet, only be identified to genus. These problems with identification greatly limit any detailed analysis of changes in the vegetation.

It is difficult to assess the extent to which a pollen sample is reflecting regional as opposed to local vegetation pattern. For example, beyond the tree-line alder appears to have a patchy distribution. High alder percentages may reflect local abundance rather than a widespread regional distribution. Similarly,high percentages of Cyperaceae may be a consequence of local over-representation when sedges are abundant at the lake margin.

Differential migration rates, multiple refugia, and changing combinations of environmental factors can further complicate the task of interpreting fossil pollen spectra (Schweger, 1976). The lack of success in tracing the origin and spread of spruce and alder in Alaska reflects these complications. It makes it difficult to determine whether the arrival of spruce in a region is in response to increased climatic warming or whether it is the consequence of the natural rate of migration of the species after the withdrawal of the Wisconsin ice in the absence of subsequent climatic warming. More well-dated pollen records and a better understanding of the ecological requirements of many species are necessary to clarify these problems.

Modern surface samples are critical to the reconstruction of patterns of fossil vegetation. Use of modern surface samples have several limitations. Certain vegetation types will be under-represented, either because the pollen is readily destroyed or because the taxa produce little or no pollen. Modern surface samples have been shown to vary greatly within regions. Andrews and others (1979) showed considerable variation in the percentages of major taxa among different sites from Pangnirtung Pass on Baffin Island, N.W.T., Canada. Ritchie (1974) working in the Canadian Arctic has shown that samples from lake sediments are much more consistent than moss polsters. No modern analogues can be found to match some fossil spectra. An example is the Artemisia maxima found in tundra diagrams by Colinvaux (1964).

The lack of surface samples for the Arctic is another problem. A number of workers, including Livingstone (1957), Colinvaux (1964), Lichti-Federovich and Ritchie (1968), Matthews (1970), Rampton (1971), Ritchie (1974), Ager (1975) and Schweger (1976), have collected modern surface samples in the Arctic. Many of these samples have been collected from moss polsters or forest turf; they are not derived from comparable sites of deposition in topographically similar areas so cross-matching in space must be carried out with caution.

A few modern surface samples were collected from the Imuruk Lake area by Colinvaux (1964). They are characterized by 20-30 percent birch and alder, 5-7 percent spruce, 10-20 percent Cyperaceae, and 5-7 percent Gramineae. This resembles the upper Zone L in Colinvaux's (1964) Imuruk core. None of the zones except Zone L on Imuruk Core V closely resemble this modern spectrum. No surface samples are available from the Whitefish Lake area.

Imuruk Lake

Vegetation History

The previous discussion underlined the problems of reconstructing past vegetation from pollen diagrams. The only part of Imuruk Core V that resembles modern surface spectra at all closely is Zone G_1 which has lower levels of alder than today.

The dwarf birch Betula nana is present at 10-30 percent in Zone G. Although the pollens of dwarf and tree birch are difficult to distinguish, tree birch pollen is only likely in Zone i when the maxima of arboreal species occur. Birch declines in Zone H and declines again to lower levels in Zone J following the maxima in Zone i. This probably reflects colder climatic conditions in Zones H and J. The more or less complete suppression of birch pollen in parts of Zone H appears to reflect the most extreme cold conditions of the record.

Throughout the diagram, increases in alder are concurrent with increases in spruce, although alder tends to grow beyond the spruce line in the Arctic. Unlike its preference for wet sites in temperate regions, alder in the Arctic is often found at well-drained dry sites. In the north Seward Peninsula, near Whitefish Lake, alder flourishes in areas where there are ash deposits. These sites are well-drained with a deep permafrost layer (Racine, pers. comm., June 1979). Hopkins (1959b) suggested that in Alaska, spruce forest was limited to areas with at least 130 degree days per year when the temperature reaches or exceeds 50^{o}F. If this was so in the past, Zone G experienced similar temperature conditions as today. In Zone H spruce declines to trace levels, presumably as the spruce withdrew further from the lake in response to cooler summer temperatures. In Zone i, spruce reaches an early maximum of more than 40 percent. Comparison with modern surface samples from forested sites in the Arctic strongly suggests that spruce reached or came very close to Imuruk Lake. Today white spruce is found as close as 25 km from Imuruk Lake, growing on dry slopes beside the Kugruk River (Racine, pers. comm., June 1979). Lichti-Federovich and Ritchie (1968), Matthews (1970), Ritchie (1974), Ager (1975), and Schweger (1976) all show comparable levels of spruce at forested sites containing similar taxa. However, plant macrofossil evidence at Imuruk would be very desirable to confirm this conclusion. Spruce declines in Zone i_2 to trace levels in Zone J.

Levels of willow are rather constant throughout the diagram, seldom rising above 10 percent. The pollen cannot be identified with confidence to species level, and willows are poor pollen producers so the willow curves impart little information.

The curve for Ericaceae pollen never rises above 10 percent. In Zones G and i, it is fairly consistently about 5 percent. In Zones H and J the ericaceous curve is consistently at trace levels probably reflecting suppression of growth by colder temperatures.

The significant maxima of Artemisia have already been noted in pre-Holocene tundra diagrams. No modern analogues exist in which Artemisia species are as widespread as these percentages suggest. According to Hulten (1968), eight of the species of Artemisia described from the Seward Peninsula are found on rocky or sandy slopes and bare exposed ground. Hopkins (1954) associated periods of loess deposition with cold glacial times. If it is correct to assume that the general habitat preference of the genus today is similar to that of the past, such conditions would be suitable for widespread growth of Artemisia species.

Percentages of grass and sedge are highest in Zones H, the upper part of i_2, and in J. These are zones in which other taxa reflect cooler climatic conditions. Arctic sedges tend to be prevalent on wet sites and grasses on mesic sites (Andrews and others, 1979). The ratio of grass to sedge pollen tends to be about 2:1 throughout the diagram. This prevalence of grass over sedge pollen could reflect the mesic and drier conditions that are correlated with the Artemisia maxima. Without identification of grasses and sedges beyond family level and without more comparative information about rates of pollen production for grasses and sedges, environmental interpretation has to be exercised with care.

The Sphagnum curve coincides with increases in spruce. Rampton (1971) showed a similar pattern. This suggests that warmer temperatures favor more growth and spore production of Sphagnum species. Unfortunately there is little evidence in the literature to support or refute this suggestion.

The minor elements impart little ecological information and most of them are in such small amounts that interpretation is not possible. The extended maxima of Lydopodium annotinum in Zones i_1 and i_2 are of interest but difficult to explain.

In summary, the pollen profiles reflect three major tundra types. Zone H and Zone J represent cold grass-sedge Artemisia tundra where dwarf birch is present in very low quantities. Zone G represents a period of dwarf shrub tundra where warmer conditions allow increased development of birch and very slight but persistent increases in levels of alder and spruce. The increase in spruce and alder pollen in Zone i suggests that warmer summer temperatures permitted spruce and alder to advance closer to the lake than at any other time during this record.

Tundra Fires

Fires may be a regular event affecting tundra vegetation. For example, two major fires occurring in 1977 in Alaskan tundra were documented. Hall and others (1978) estimated 44 km^2 of burned area in the Kokoli River area of northern Alaska. In the Seward Peninsula Racine and Racine (1979) reported that one fire burned about 958 km^2 over a large area south of Deering and north of Imuruk Lake between the Imnachuk and Kugruk Rivers. At many sample levels in the Imuruk core charcoal fragments are abundant. No quantitative record of their occurrence was made. Further investigations of the frequency and affect of fires on tundra vegetation and the possible relationship between fluctuations of certain pollen taxa and the occurrence of charcoal fragments in the sediment record could be very profitable.

Suggested Climatic History

As much care must be exercised in making climatic interpretations from the vegetation as in reconstructing the vegetation from the pollen. When compared to modern surface samples, the fossil record suggests two long periods, Zones H and J, when the climate was colder than today. Sub-zone H^{ii} seems to be a short period of climatic warming. The pollen curves of Zone G, apart from the high levels of *Artemisia* in G^{ii} and G^{iii} and the low levels of alder throughout the zone suggest temperatures similar to the present. More modern surface samples from lake sediments in the Imuruk area might help to substantiate this. Zone i_1 suggests a period of time when the climate was at least as warm and possibly warmer than today.

In summary, the record starts with a zone when conditions were probably similar to those of today. This is followed by a cooler and probably drier zone. Colder and drier conditions would be associated with a lowering of sea level, exposure of the Bering Land Bridge, and increasing continentality of the Imuruk Lake region. This dry cold period is followed by what appears to be a warm interstadial zone which undergoes a gradual transition to colder conditions again. The upper part of the diagram briefly indicates a change to warmer Holocene conditions.

Whitefish Lake

Vegetation History

The Whitefish Lake record shows remarkably little change throughout at least the past 10,000 years. Despite the problems in understanding the similarity between the two lower dates (see below), the high levels of alder at the bottom of the diagram suggest that the record is not much older than 10,000 years. Alder is localized geographically on the Seward Peninsula. It is especially common near the Maar Lakes in the Whitefish region (Racine, pers. comm. 14 June, 1979). Around Devil Mountain Lake and the Killeak Lakes, Racine noted that it preferred the ash deposits that are well-drained and presumably have a deep permafrost layer. So rather than reflecting a primarily climatic influence, the high levels of alder probably reflect suitable local soil conditions. The Artemisia is present in trace amounts, which is typical of Holocene tundra conditions. The record is similar to that of Zone III of Livingstone's (1955) three zone sequence for post-glacial time in the Arctic. Zone III represents low Arctic tundra.

Comparison to Other Selected Holocene Records from the Arctic

Leopold in Hopkins and others (1960) found little evidence for climatic change during the last 8,000 years from pollen analysis of a peat deposit from Nome on the south coast of the Seward Peninsula. McCulloch and Hopkins (1966), Colbaugh (1968), and Detterman (1970) have produced rather equivocal evidence for an early warm period between 10,000 and 8,000 B.P. There is no evidence for this early warm period in the Whitefish core.

There is better evidence for a mid-Holocene warm interval in Alaska comparable to the European Hypsithermal, reported by Livingstone (1955; 1957) from the Brooks range, Colinvaux (1967b) from St. Lawrence Island, and Ritchie and Hare (1971) from the Arctic coast east of the Mackenzie River delta. Livingstone identified the beginning of the Hypsithermal interval by a dramatic increase in alder pollen. Only one of his cores is dated (Livingstone, 1957) with a date of 5,900 ± 200 just below the alder rise. Because the core is truncated, there is no evidence that there is a subsequent decline in alder. Colinvaux (1967b) demonstrates a spruce and alder rise from Flora Lake on St. Lawrence Island at about 6,000 B.P. Ritchie and Hare (1971) identify a mid-Holocene warm interval on the basis of an increase in spruce. Each of these studies could reflect vegetation changes independent of a warming period. Their appearance on the diagram may simply be a function of migration rates and location of Wisconsin refugia. More closely dated pollen records from more Arctic sites are needed to reconstruct patterns and rates of migration, such as have been done for Pinus strobus in the mid-west by Watts (1973). The pollen record from Whitefish does not reflect any obvious changes in the vegetation throughout the Holocene. This may be because Whitefish Lake is too far beyond the tree-line to record changes in its position.

Suggested Climatic History

The pollen record suggests that the climate has remained unchanged during the past 10,000 years in this region. However, this does not exclude the possibility of climatic change occurring which has not been registered in the pollen record.

The Origin of the Alaska Spruce

There has been much controversy as to the origin of spruce in the early Holocene (Hopkins, 1972). Did spruce persist during the glacial period somewhere in Beringia or did it reinvade at the end of the Wisconsin from somewhere in Alberta or Montana south of the Cordilleran and Laurentide Ice Sheets? Hopkins (1972) postulates a refugium in south central Beringia where moist, mild summers would allow spruce to persist. Apart from Colinvaux (1967c) finding large quantities of spruce pollen in a core from Saint Paul Island in the Pribilofs dated older than 9,500 B.P., there is little pollen evidence to support Hopkins' hypothesis.

Low levels of spruce pollen throughout the Whitefish record indicate that if there was an Alaskan spruce refugium, it was far from this region.

DATING

Imuruk Lake

The core has been dated using radiocarbon (Table 3) and paleomagnetic methods by Marino (1977) and also by fission track dating.

Radiocarbon Dating

^{14}C Dates above 1.5 m.

Figure 11 displays depth-age plots for dates from Imuruk Lake Core I (Colinvaux, 1964; Colbaugh, 1968), Core II (Colbaugh, 1968), Core IV (Colbaugh, 1968), and Core V (Marino, 1977). Core V dates indicate a very high sedimentation rate in the upper 1.5 m, especially compared to Core I. However, within the range of error of the dates there is a good match in sedimentation rates between Cores IV and V which were collected 1 meter apart. The high sedimentation rate appears to be largely attributable to very heavy blooms of Pediastrum spp., which prevented pollen counts in most of the upper meter in Core V. One c.c. samples of sediment at 11.0, 17.0, 28.0, 38.0, 46.0, 57.0, and 70.0 cm. contained approximately 0.5, 0.5, 0.3, 0.4, 0.2, 0.15, and 0.35 c.c. of Pediastrum cells, respectively. Pediastrum was never as abundant in any other part of the core. In the upper meter of Core IV Colbaugh (1968) found high levels of Pediastrum. Colinvaux (1964) also found high levels of Pediastrum in the upper part of Core I but Figure 11 shows a very different sedimentation rate. The cause of the Pediastrum blooms is not obvious. Prescott (1963) observed Pediastrum blooms in a lake near Point Barrow, but so far there is little information as to what environmental factors would cause such blooms in the Arctic. If there was nutrient enrichment, this appears to have persisted for several thousand years until the sediment record was truncated.

^{14}C Dates Below 1.5 m.

The date of $24{,}190 \begin{smallmatrix}+960\\-1070\end{smallmatrix}$ B.P. at 160.1-173.3 cm on Core V matches Colbaugh's (1968) date of 25,850 ± 2,400 B.P. at 172-184 cm on Core IV.

For several reasons it is not possible to extrapolate down the core from these dates with any great accuracy. The depth-age relationship is not linear. Yamamoto and others (1974) have shown on the Biwa Core that there is an exponentially changing relationship of age to depth as sediments compact. It is also unreasonable to assume that sedimentation rates were uniform throughout such a long period of time.

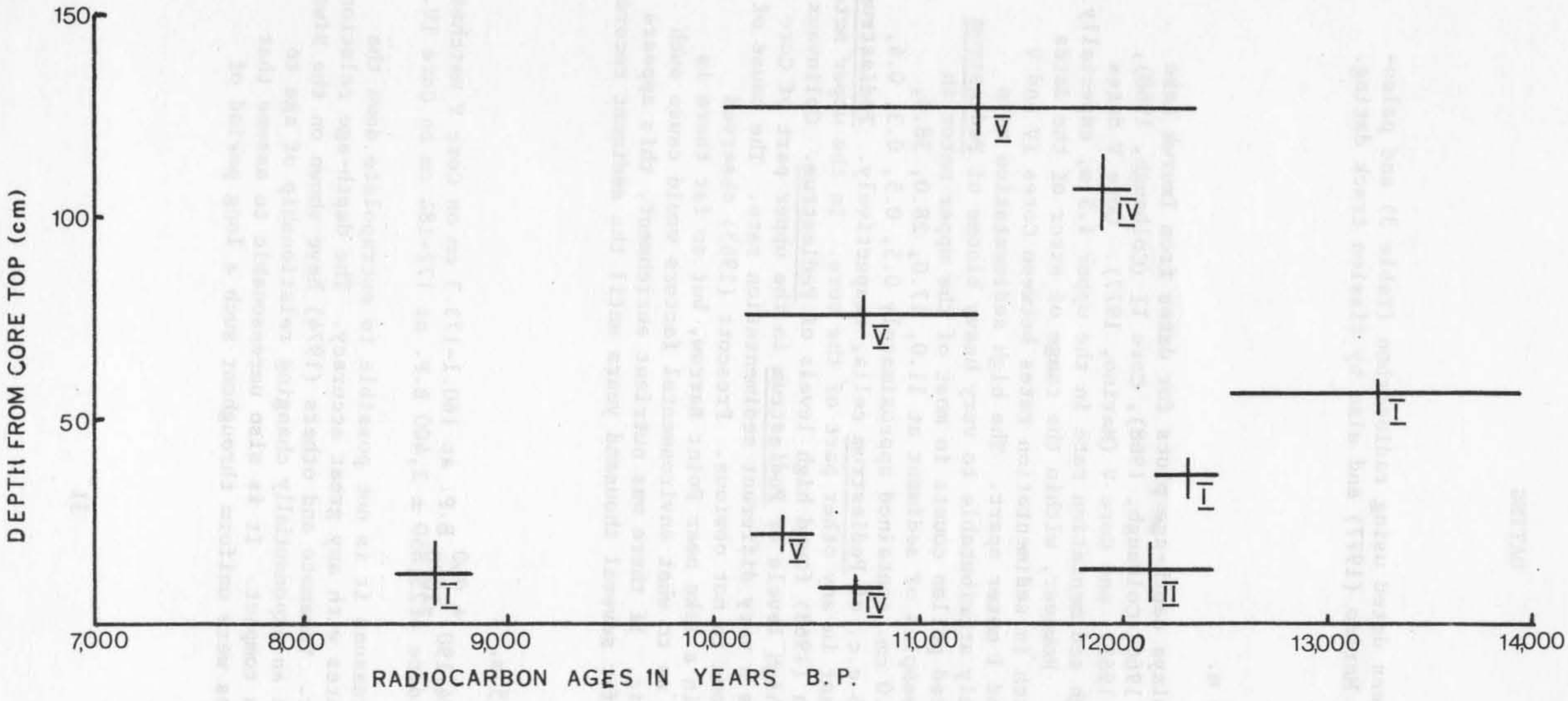

Figure 11. Depth-age points for upper 1.5 m on Imuruk Lake cores.

Paleomagnetic Dating

Marino (1977) identified three geomagnetic excursions on Core V. His findings are summarized in Table 5.

Comparison of Paleomagnetic and Radiocarbon Dates

An extensive literature survey by Marino (1977) indicates a large number of "events," "excursions," "happenings," "departures," and "flips" have been reported for the past 150,000 years. There are few data from sites close to Imuruk except for the excursion found at Imuruk by Noltimier and Colinvaux (1976). It was dated by ^{14}C at 17,600-18,700 B.P. Marino's (1977) upper excursion fits quite well with the radiocarbon date and Creer and others (1976) Erieau Excursion. The middle excursion is centered on the radiocarbon date of 24,190 $^{+950}_{-1070}$ B.P. This agrees with dates elsewhere for such an excursion (Denham, 1974; Liddicoat, and Coe, 1975).

By extrapolation the Blake Episode occurs somewhere between 106,000-136,000 B.P. Dates from elsewhere for a similar event are not precise. Except for Yaskawa (1974) at Biwa, most other dates are based on paleontological correlation or assumed sedimentation rates.

The comparisons are tentative and the absence of excursions in this Imuruk core that occur elsewhere suggest that interpretation based on the paleomagnetic data be made with great caution.

Occurrence of the Blake Paleomagnetic Event

Marino and Ellwood (1978) have cast doubt on the real occurrence of this event in Imuruk Core V. Their conclusion is reached on the basis of the anistropy of magnetic susceptibility which in the excursion sediments exhibits an anomalous distorted fabric.

While the paleomagnetic study obviously requires further cores to be analyzed to support these conclusions, the magnetic inclination shallowing does occur at a point in time which relates to similar excursions elsewhere. The x-radiographs and arguments presented by Colinvaux (1964) do not support the occurrence of disturbance or turbidity suggested by Marino (1977). The paleomagnetic study at the very least makes plausible an age of 140,000 years for the core, suggesting that it penetrates to the Sangamon interglacial.

Fission Track Dating

It is hoped to obtain a date from the ash layer between 525 and 535 cm on the Imuruk V core. Samples have been submitted to Dr. J.

TABLE 5.--Summary of Results of Paleomagnetic Study by Marino, 1977

Depth of Excursion on the Imuruk Core in cm	Excursions Identified at Other Sites With Which These May be Tentatively Correlated	Dates of Occurrence of Correlated Excursions in Years B.P.	Dating Method
7.5-24.1	Erieau Excursion - Creer and others, 1976	7,600-10,500	Sedimentation rate and glacial stratigraphy
151.3-185.8	Mono Lake Excursion - Denham, 1974	24,000	Radiocarbon and stratigraphy
	Liddicoat and Coe, 1975	24,600-25,000	Radiocarbon
601.1-624.5	Blake Episode - Smith and Foster, 1969	108,000-114,000±10%	Paleontological correlation and sedimentation rate
	Yaskawa, 1974 at Lake Biwa	104,000-117,000	Extrapolated radiocarbon dates and fission track
	Denham, 1976	100,000 (deviation 16,500 years)	Paleontological correlation

Sutter (Fission Track Dating Laboratory, Department of Geology and Mineralogy, The Ohio State University) to obtain an estimate of the age of the layer. No results are yet available. A date from this part of the core would be of great interest because it is beyond the range of radiocarbon dating and a date could help to test the validity of the Blake event on this core.

Whitefish Lake

Radiocarbon Dating

The dates on Table 4 indicate that the core provides a record for at least the past 10,000 years. The similarity between the two lower dates is disconcerting. There is no obvious reason to suspect contamination. Confidence in the bottom date of 10,200 ± 550 B.P. is greatly limited by problems that Geochron Laboratories had in analysing the sample. The original date of 9,390 ± 350 B.P. that they determined from the sample was subsequently adjusted by them because of abnormal fluctuations in atmospheric pressure when the sample was being processed. Further dates have been submitted for radiocarbon dating in order to clarify this problem.

Paleomagnetic Dating

There are no distinctive magnetostratigraphic occurrences; there is a regular pattern of declination variation. Marino (1977) predicted an age of 8,000 years for the core. This does not closely match the radiocarbon dates so far available which suggest an age of at least 10,000 B.P.

POLLEN ANALYSIS AND THE CLIMATIC RECORD FROM THE SEWARD PENINSULA DURING THE LATE PLEISTOCENE

Imuruk Core V and Whitefish Lake Core

The five main zones on Imuruk Core V and Whitefish Lake Core suggest the following glacial sequence during the past 140,000 years: inter-glacial, glacial, interstadial, glacial, inter-glacial. Dating of the lower part of the core is based on tentative paleomagnetic data and extrapolated radiocarbon dates which will be very sensitive to changes in sedimentation rates. With these circumstances in mind, the zones can be assigned to the following glacial episodes.

Zone G spans the latter part of the Sangamon interglacial and lasts from about 140,000 B.P. until about 80,000 B.P.

Zone H appears to span the early Wisconsin glacial period and may have been from about 80,000 B.P. until 55,000 B.P. A fission track date from the ash layer should help to date the beginning of this period.

Zone i_1 represents the mid-Wisconsin interstadial which began about 55,000 B.P. and was over at about 25,000 B.P. although the cooling trend seems to have started considerably earlier. Maximum cold glacial conditions of the late Wisconsin were reached about 20,000 B.P. and persisted until at least about 11,000 B.P.

During the past 10,000 years, the pollen record from Whitefish suggests an unchanging non-glacial climate in the northern Seward Peninsula. The pollen record may have been affected by the local influence of a maritime climate.

Correlation With Other Evidence for Glacial Events in the Arctic

There is remarkably little evidence available to indicate the time of occurrence and duration of pre-Holocene glacial events in the Arctic. Péwé (1975), in a review of the Quaternary geology of Alaska, was not able to differentiate between stages of the Wisconsin period. Hopkins (1972) did not discuss climatic changes in Beringia for the period between 70,000 and 20,000 B.P. because details of climatic, glacial, and sea-level history were still poorly understood.

Colinvaux (1964), in the first of his two alternative correlations of the pollen records with glacial events, proposed a scheme similar to that proposed for Imuruk Core V although the early Wisconsin stage was of much shorter duration. Colbaugh (1968) assigned Zone J_2 to the Wisconsin and Zone i to Sangamon time following Colinvaux's (1964) second alternative correlation which subsequently appears not to fit.

Peat 5 from the Deering formation at Cape Deceit was suggested by Matthews (1974) as possibly similar to Imuruk J_2 of Colbaugh (1968). However, these sediments revealed a spruce tree line closer to Deering than at present. Reinterpretation of when the interstadial occurred at Imuruk now suggests a similar pattern between Cape Deceit and Imuruk Core V.

Correlation With Glacial Events Outside the Arctic

Information on the chronology of climatic change during the Quaternary has been derived principally from examining changes in oxygen isotope ratios in deep sea cores. More recently the range of radiocarbon dating has been extended to 75,000 B.P. for North America by Stuiver and others (1978) and for northwestern Europe by Grootes (1978). Stuiver and others (1978) identify three interstades near 60,000, 65,000, and 70,000 years ago. Three early glacial interstades occurring at similar dates were identified by Grootes (1978) for northwestern Europe. However, the radiocarbon chronology does not agree very closely with interpretations of the deep sea record (Shackleton and Opdyke, 1973). Grootes (1978) suggests a date of 55,000 B.P. for the onset of the early Wisconsin cold period. Dansgaard and others (1971), from oxygen isotope measurements the Camp Century Ice Core, suggested a date of 73,000 B.P. for the onset of the Wisconsin. This date is closer to the date that the Imuruk record suggests.

Klein (1971) suggests a three-phase sequence based on pollen analysis for the last glacial in Siberia: the Zyryanka Stadial (70,000-?50,000 B.P.), the Karginskij Interstadial (50,000-30,000 B.P.), and the Sartan Stadial (?30,000-10,000 B.P.). There is a good broad agreement between the Siberian chronology and the proposed sequence for Imuruk Core V.

The new Imuruk record, therefore, contributes important new data on the chronology of the Ice Age, particularly as to the duration of the major cold and warm intervals.

SUMMARY AND CONCLUSIONS

Sediment cores from Imuruk and Whitefish Lakes have been analyzed for pollen and dated using radiocarbon techniques. The paleomagnetic study by Marino (1977) has greatly extended the range of the radiocarbon dating by providing evidence for the occurrence of the Blake paleomagnetic event which occurred 100,000-125,000 years ago. Imuruk Core V appears, therefore, to be about 140,000-150,000 years old. Radiocarbon dates showed that the record was truncated about 10,000 years ago. Pollen analysis, supported by these dates, suggests that the Wisconsin in the Arctic consisted of three major phases: a cold period when the vegetation was dominated by Gramineae, Cyperaceae, and *Artemisia*, this being the steppe-tundra first described by Colinvaux (1964). This lasted from about 80,000 until 55,000 B.P. Then there was a warmer interstadial when *Betula*, *Alnus*, and *Picea* became much more abundant between 55,000 and 35,000 B.P. Finally there was another cold period with steppe-tundra vegetation which began about 35,000 B.P. and lasted until 10,000-15,000 B.P. This chronology is very similar to that suggested by Klein (1971) for Siberia. However the dates are not precise and the history may be found consistent with the dating of glacial events from other parts of the world. There is evidence from Imuruk to suggest that the Wisconsin was preceded by a long period of declining temperatures during the Sangamon. The vegetation then consisted of shrub tundra with *Picea* and *Alnus* often above trace amounts.

The Whitefish Lake record spans at least the past 10,000 years. The pollen record, the first Holocene record from this region, reflects a vegetation in which Cyperaceae and *Alnus* are abundant. The record indicates that there was no significant climatic change during the Holocene.

This study provides the best dated, well documented, long Arctic pollen record that gives a good history of the major vegetation changes and, hence, a good indication of the nature of the climatic record of the Wisconsin in the Arctic.

APPENDIX A

LABORATORY PROCEDURE FOR PROCESSING
ARCTIC POLLEN SAMPLES

1. 0.5 or 1.0 c.c. subsamples were taken from the core and placed in 15 ml. graduated polypropylene centrifuge tubes.

2. To each tube add preweighed <u>Eucalyptus</u>[1] tablet (Batch number 903722 from L.J. Maher, Jr.).

3. Add 5 ml. 10 percent HCl to digest the carbonate, warming in a hot water bath if necessary. Centrifuge and decant.

4. Add 5 ml. of 5 percent NaOH to each tube, mix well and place tubes in a boiling water bath for 30 minutes. Centrifuge and decant.

5. Wash sample with double distilled water, centrifuge and decant.

6. Repeat step 5.

7. Wash sample with glacial acetic acid. Centrifuge and decant.

8. Add 6 ml. of 40 percent HF very carefully (in the fume hood) using protective shield and rubber gloves. Leave in boiling water bath for at least 1 hour. Preferably then leave samples overnight. Stir samples at regular intervals while in the water bath.

9. Add 9 ml. of 95 percent EtOH to each tube (to reduce the density), mix well, centrifuge and decant into a waste container for HF.

10. Add 5 ml. of glacial acetic acid, mix, centrifuge and decant.

11. Repeat step 10.

12. Add acetolysis mixture (9 parts acetic anhydride, 1 part conc. HSO), mix, and place tubes in boiling water bath for at least 5 minutes and maybe, depending on the nature of the organic material present, for as long as 30 minutes so that the mixture turns dark brown and thick.

13. Let cool for a few minutes, then centrifuge and decant.

14. Add glacial acetic acid, mix, centrifuge and decant.

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[1] <u>Eucalyptus</u> tablets. Counts were made by R. Brugam on 30 sample tablets using a Coulter counter while working with M.B. Davis. Grains per m.g.: 182.065 ± 4.1607 at 95 percent confidence interval, Standard Deviation 11.6271. (Pers. comm. from Henry Lamb, Limnological Research Center, University of Minnesota, Minneapolis, December 1977.)

15. Add distilled water, mix, centrifuge and decant.

16. Repeat step 15.

17. Add acetone, mix, centrifuge and decant.

18. Repeat step 17.

19. Repeat step 18.

20. Add 3 ml. of bromoform-acetone mixture[2] (adjusted to a specific gravity of 2.0), mix well, centrifuge and decant into tube B (polypropylene).

21. Repeat step 20 so that tube B should have 6 ml. of heavy liquid.

22. Adjust volumes of all tubes to 6 ml., mix, centrifuge and pour off into tube C (glass), containing 9.5 ml. of acetone. Discard tube B.

23. Carefully mix contents of tube C, centrifuge and decant into a bottle so that the bromoform can be reclaimed.

24. Wash contents of tube C with acetone, mix, centrifuge and decant.

25. Repeat step 24.

26. Repeat step 25.

27. Wash with distilled water.

28. Repeat step 27.

29. Add 10 ml. 95% ethanol and 1 drop of safranin (1 gram in 200 ml.). Mix, centrifuge and decant.

30. Add tertiary butyl alcohol, mix, centrifuge and decant.

31. Repeat step 30. (If there is sufficient quantity of the sample to store in glass vials, transfer from the glass test-tube after mixing during this step.)

32. Add silicone oil (2,000 centistokes)[3] equal in amount to about twice the volume of sediment.

33. Transfer using a disposable glass capillary pipette to a slide.

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[2] Several persons (Ton Ager of U.S.G.S. and Pat Anderson of Brown University) have strongly advised me against the use of bromoform because of its danger to one's health.

[3] See Anderson (1960) for use of silicone oil as a mounting medium for the pollen grains.

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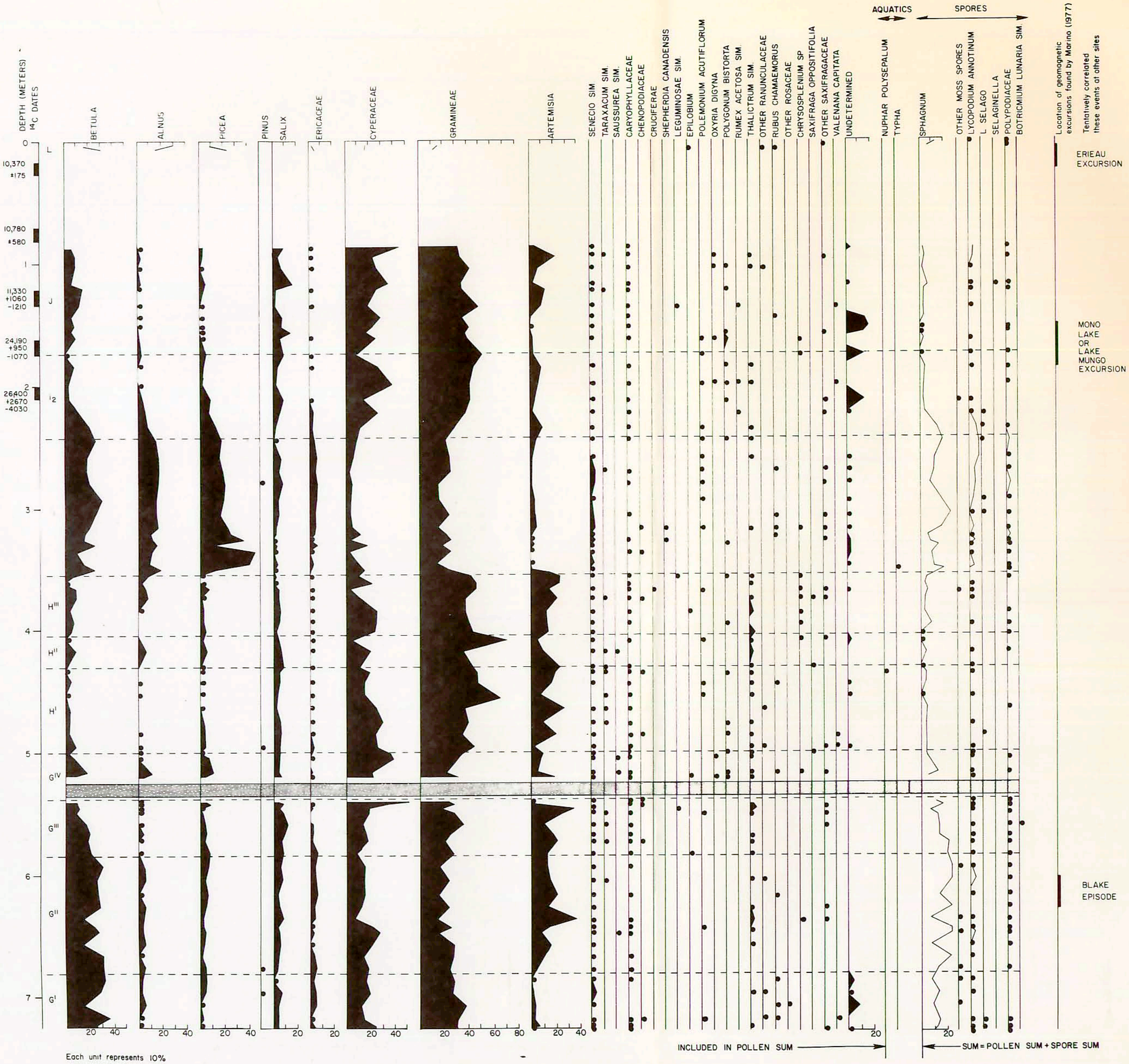

Each unit represents 10%
● Represents 2% or less
▭ = Ash layer

Fig. 4 POLLEN PERCENTAGE DIAGRAM, IMURUK LAKE, CORE V

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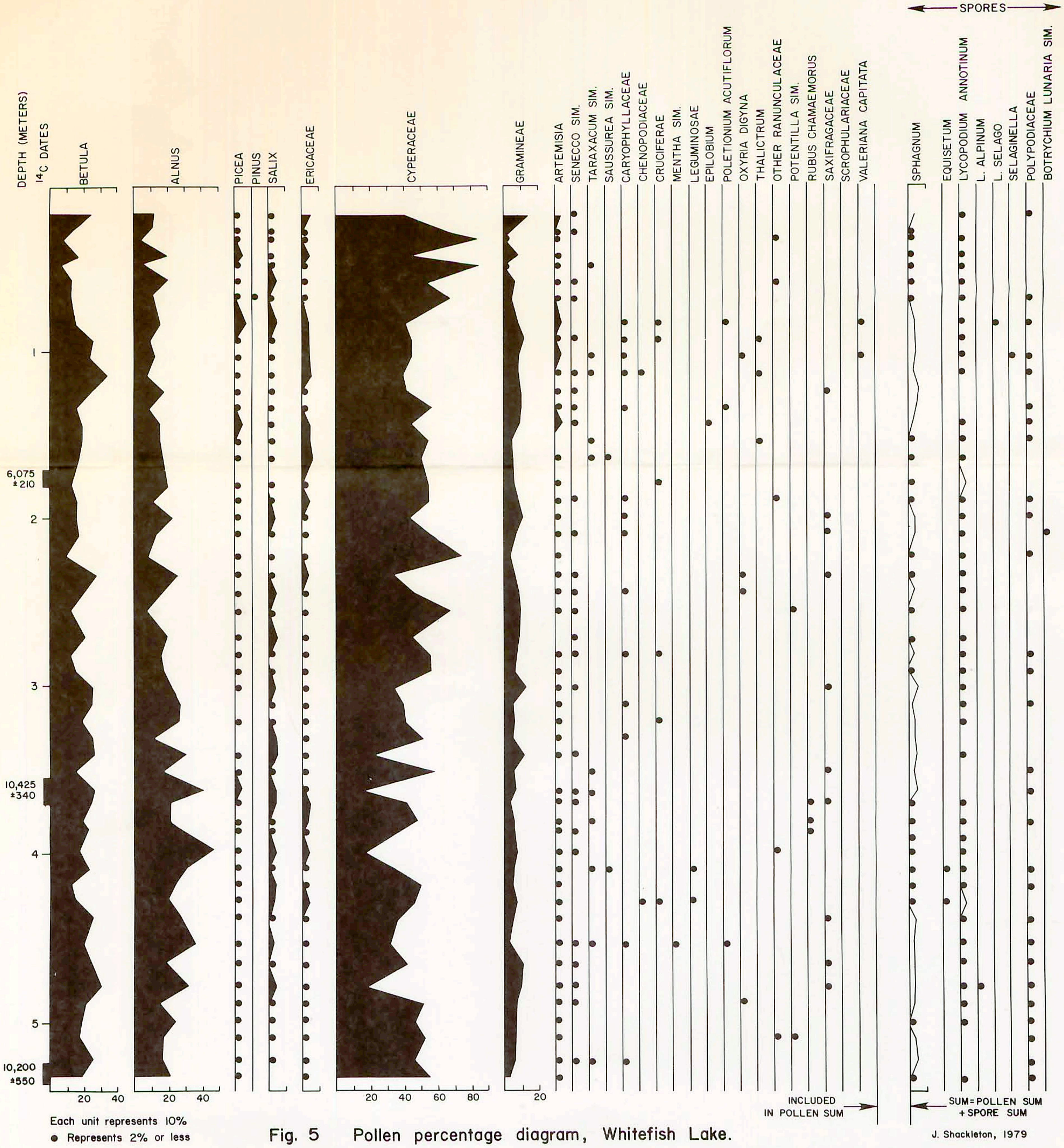

Fig. 5 Pollen percentage diagram, Whitefish Lake.

J. Shackleton, 1979

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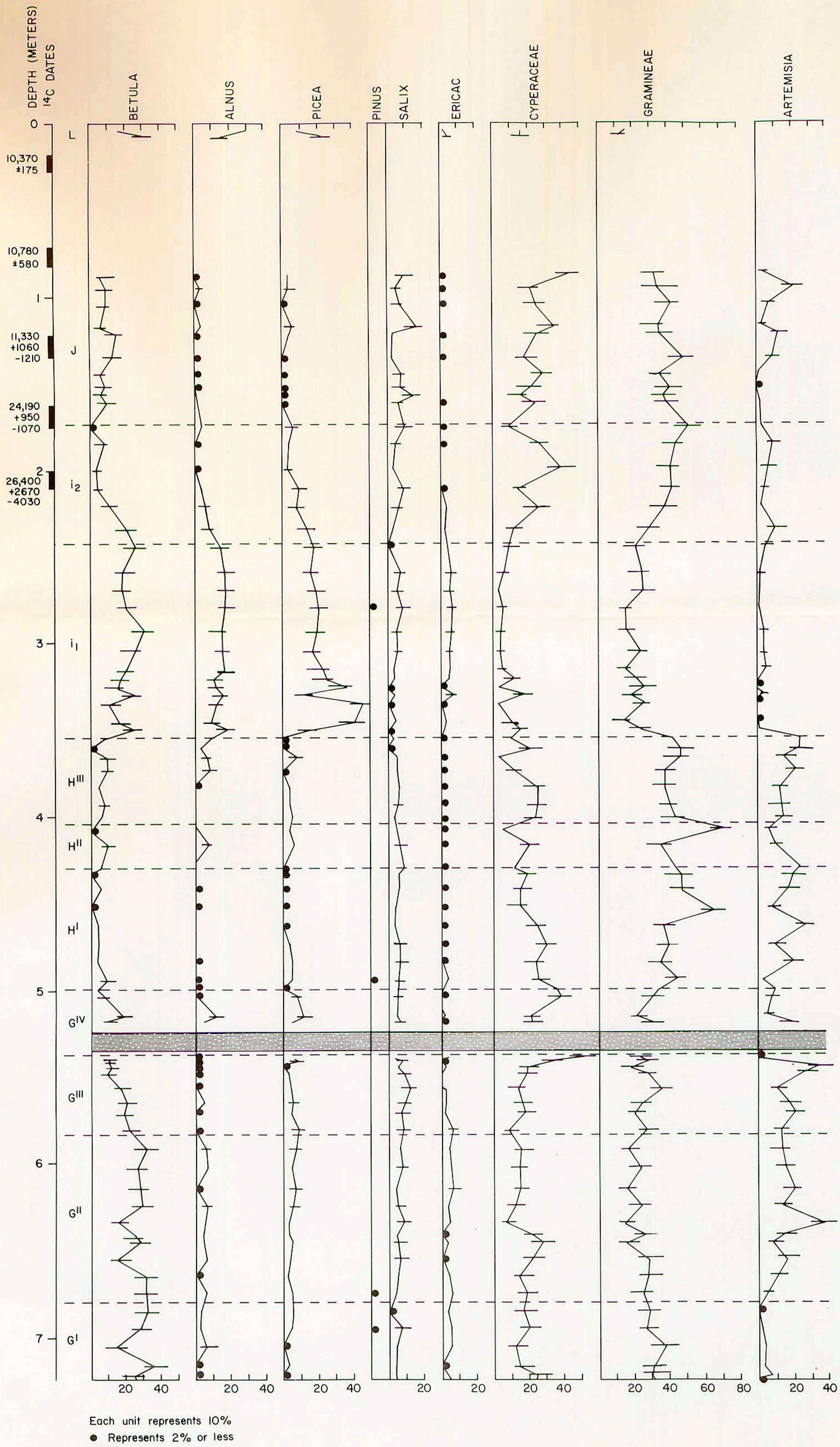

Each unit represents 10%
● Represents 2% or less
= Ash layer

J. Shackleton, 1979

Fig. 9 Imuruk Lake, 0.95 Confidence Limits for major taxa.

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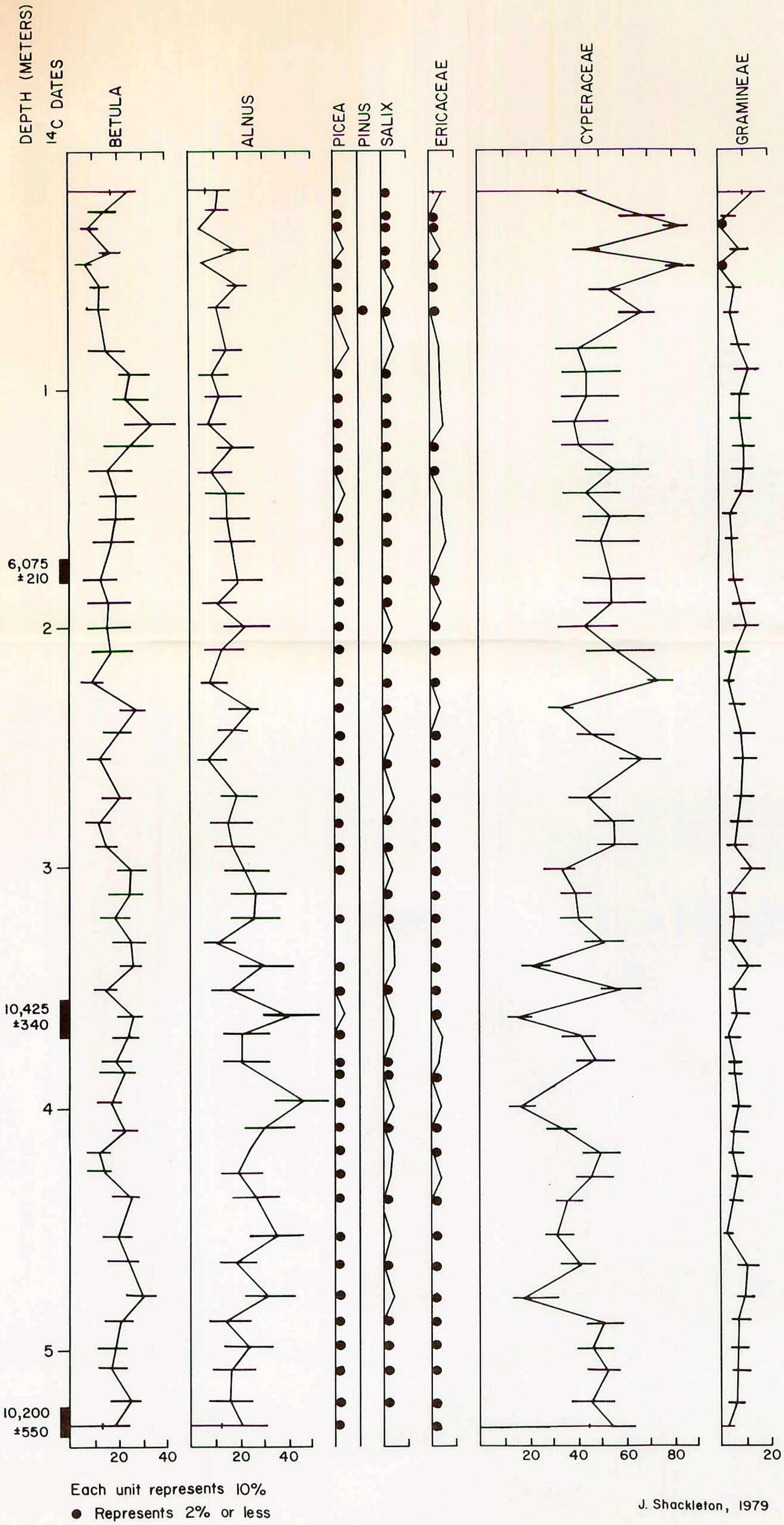

Fig. 10 Whitefish Lake, 0.95 Confidence Limits for major taxa.

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